Performance of Mortar Incorporating RHA Under Elevated Temperature

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Abstract-- **Mortar is one of the important components of concrete. At the time of fire in structure, the mortar faces the major problem and finally becomes debonded or spalled. At the time of fire different techniques were applied to control it. Applying of water jet is one of the techniques. The performance of mortar subjected to high temperature was examined in this work. Six series of cubical 5cm × 5cm × 5cm mortar specimens were cast from OPC with partial replacement (10, 15, 20, 25 & 30%) of OPC by Rice Husk Ash (RHA). ASTM graded sand was used as fine aggregate. After 90 days curing in laboratory condition these specimens were heated in electric furnace to 200, 300, 400, 500 and 700 ^{o}C for 30 minutes. After burning the specimens were removed from the furnace and kept in normal environment and quenched with water for 10 seconds and then kept in ambient temperature to loose the heat. After one day from heating samples were then tested. In this work it was observed that the strength was higher than the controlled sample up to 20% replacement levels under elevated temperature.**

Keywords: Rice Husk Ash, Temperature, OPC, quenched.

I. INTRODUCTION

The purpose of this work is to study the performance of mortar incorporation with rice husk ash under the influence of high temperature on microstructure and mechanical properties. Fire is one of the most serious risks and creates serious problem in any structure. Any building may be caught by fire at any time. Most of the structural materials exposed to firing at high temperature are weakened which is not visible. Hence the study on the performance of structural elements under fire has become more and more important.

An increasing number of research works in this field are being done. A very important portion of the fire on cofcrete is degradation of mechanical properties of concrete. This problem has been studied since 1950's [1,2,3]. Nijland and Larbi reported that concrete heated by fire might result in a variety of structural failure such as cracking, spalling, debonding of aggregate from mortar, expansion, loss of strength and mineralogical/chemical changes [4].

The researchers stated that when a concrete structure is exposed to fire, differential expansion and contraction of various components and constituents within the concrete take place. St. John et al. stated that with regard to cement paste, evaporation, dissolution, dehydration and dissociation of ettringite, gypsum, calcium hydroxide, calcium carbonate and other phases such as calcium silicate hydrates in the cement paste may be found due to the fire effect [5]. Hansen and Ericsson studied the effects of temperature change between room temperature and 100 ^{o}C on the behavior of cement paste, mortar and normal concrete under load [6]. Results of their investigation show that cement paste and mortal beams deflect excessively when heated after application of load. Castillo reported the effect of transient high temperature on the uniaxial compressive strength of high-strength normal concrete. The temperatures studied varied from 100 to 800 ^{o}C [7].

Several studies concerning the fire performance of Light, Normal and high strength concrete were performed, but the mortar with Rice Husk Ash is still not investigated. The references [8-10] have measured and made comments on the residual strength of the concrete under fire, claiming that concrete is one of the most fire resistant material and light weight aggregate concrete has a better fire resisting property than normal density concrete. Sarshar examined the degradation of compressive strength of cement paste specimens had been produced from Ordinary Portland Cement (OPC)

[11]. The specimens were cylindrical in shape and height to diameter ratio was 1(one). All the tested specimens' were heated up to 300 or 520 ^{o}C and then cooled in different ways. Sarshar stated that specimens cooled with water shows much greater strength reduction than those cooled slowly.

Cement mortar and coarse aggregate are the main composition in concrete and the mortars are more vulnerable under high temperature. The use of RHA in mortar and concrete as partial replacement of cement has been extensively investigated in recent years. In this research work traditional cement mortar made from OPC and modified cement mortar made from OPC and Rice Husk Ash (RHA) were used.

II. EXPERIMENTAL WORKS

A. Materials

The objective of the experimental program was to investigste the strength properties of cement mortar in presence of RHA as a supplementary material of OPC. The materials used were ordinary Portland cement (OPC) complying with ASTM Type I, ASTM graded sand as fine aggregates and RHA obtained from laboratory combustion process, which is quite similar to traditional uncontrolled combustion process available in rural Bangladesh. The chemical composition of RHA is shown in Table 1.

The mix proportion of cement mortar is 1: 2.75 by weight of material for all samples. Controlled sample is of zero percent of RHA and is designated by A0. Other samples were mixed in different proportions of RHA with OPC cement i.e. OPC cement was partially replaced by RHA. Detail mixtures of mortar with sample ID are shown in Table 2.

TABLE I

Chemical Composition of Rice Husk Ash

Constituents	Fe_2O_3	SiO_2	Al_2O_3	CaO	MgO	L.O.I.
%Composition	1.28	91.43	0.76	0.91	1.12	3.86

TABLE II

Mixing Proportion for Preparation of Mortar

Mix ID	*A0*	*A10*	*A15*	*A20*	*A25*	*A30*
% of OPC	*100*	*90*	*85*	*80*	*75*	*70*
% of RHA	*0*	*10*	*15*	*20*	*25*	*30*

B. Sample Preparation and Testing

After mixing cubical specimen of 5cm × 5cm × 5cm size were prepared for individual % of RHA. For each % of RHA samples were prepared for each range of firing tests. Hence total number of samples including control specimen is 36 for individual mixing ID. Before demoulding all samples were kept in a moist place for 24 hours. Then samples were left for curing in a water tank at 25±2 ^{o}C temperature up to the time of test. Before starting the firing tests all samples were preconditioned. It was done by two steps. First keeping those in open air for 12 hours and then heating the sample at 100 ^{o}C for 12 hours and after this, samples were taken off from oven and cooled down in open air for 12 hours. Afterwards the specimens were taken for firing tests in an electric muffle furnace. The internal chamber of furnace was 30cm × 30cm × 30cm and the maximum heating capacity was 1200^{0}C. Five series of firing tests were done at different heating ranges which are 200, 300, 400, 500 & 700 ^{o}C respectively. Firing of samples shown in Fig. 1 in each temperature was maintained for 30 minutes. A pliers made with mild steel was used to collect the heated samples from the furnace and electric switch was off before this. After removing the specimens from the furnace, they were cooled in two different ways. Three of six specimens were cooled down freely in open air at room where the temperature was 29 to 32^{o}C. Remaining three specimens of each type were quenched with water at 30 ^{o}C for about 10 seconds. After this they were also cooled down freely in the room temperature. At the time of quenching with water huge amount of vapor was produced which is shown in Fig. 2.

Figure 1: Removal of sample from Muffle Furnace

Figure 2: Quenched with water

The heating rate in the furnace shows quite similar to the ASTM E119 up to 700 ^{0}C. The maximum test temperature was 700^{o}C and the temperature increasing rate up to this was followed according to ASTM standard. The temperature within the furnace was measured by two different thermocouples at different places and determined the final temperature by mathematical average of these two. The Standard and developed temperature in furnace is shown in Fig. 3.

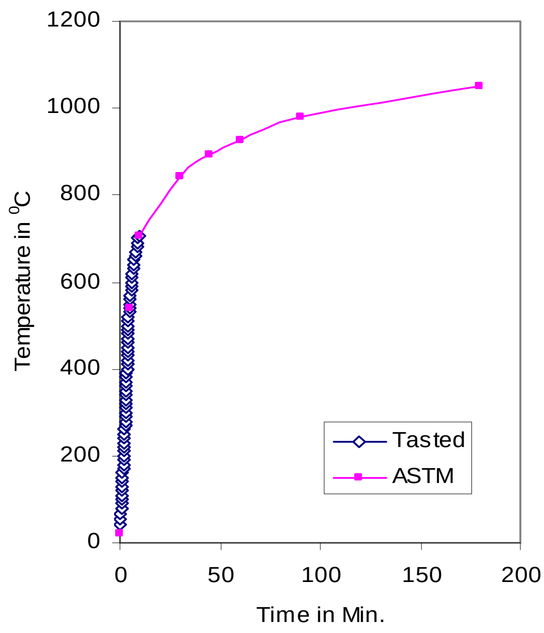


Fig.3: Time- Temperature Curve (tested and ASTM standard)

The initial temperature of the furnace in this test was maintained at 40^{o}C but in ASTM standard it is 20^{o}C. At 5 and 10 minutes the Standard temperature is 538 ^{o}C and 704^{o}C and these temperatures observed in the furnace at 4.96 and 9.45 minutes respectively. So the tested temperature was developed in furnace is very close to the ASTM standard. Samples were kept in the furnace for 30 minutes and in that time the furnace was on and maintained the last temperature. After this the samples were moved from the furnace and followed two different ways (described earlier) of cooling and then tests were performed.

III. RESULTS & DISCUSSIONS

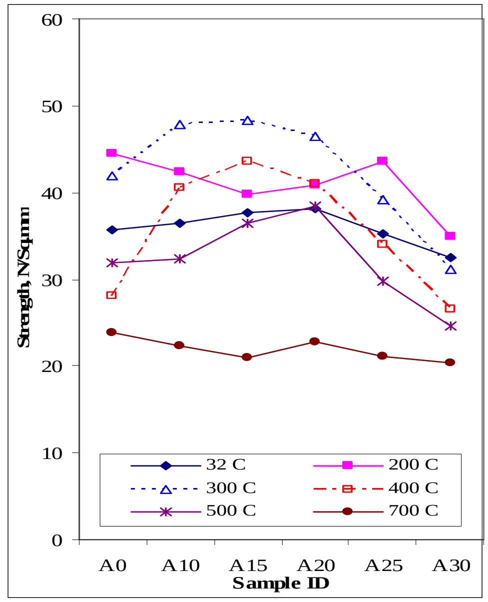
The compressive strength test of mortar sample was carried out next day after heating. All samples were tested in universal testing machine for its strength properties. At 90 day age of the sample, control specimen shows higher strength than 25% and 30 % replacement levels and at 10%, 15% and 20% replacement of OPC by RHA samples shows higher strength than the controlled sample. In this case all the samples were tested at ambient temperature and information are given in Table 3. In case of elevated temperature samples exhibited different strength when it compared with the ambient strength. At 200 ^{0}C the controlled sample showed higher strength than any other samples when it is cooled in open air after heating.

TABLE III

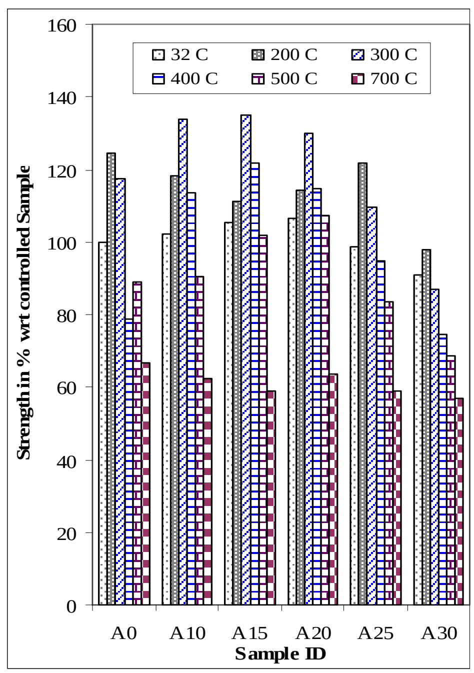
Strength variations due to Elevated Temperature and cooled in open air.

Sample ID	Temperature					
	32^0 C	200^0 C	300^0 C	400^0 C	500^0 C	700^0 C
	Strength MPa					
A-0	35.8	44.5	42.0	28.2	31.9	23.8
A-10	36.5	42.3	47.8	40.6	32.3	22.4
A-15	37.7	39.7	48.3	43.5	36.5	21.0
A-20	38.1	40.9	46.4	41.1	38.4	22.8
A-25	35.3	43.6	39.2	34.0	29.8	21.1
A-30	32.5	35.0	31.1	26.6	24.6	20.4

At 300 ^{0}C temperature controlled samples show lower values than 200 ^{0}C strength. Samples having 10%, 15% and 20% RHA exhibit increasing trend in strength up to 200 ^{0}C temperature. Samples are in all temperature exhibit lower strength than the controlled sample when the Ordinary Portland Cement was replaced by 30% RHA. At 700 ^{0}C controlled sample exhibits comparatively more strength than all other replacement levels. Controlled sample shows 66.7% and 62.6%, 63.7%, 56.9% strength were observed for 10%, 20% and 30% replacement levels respectively. At higher temperature beyond 500 ^{0}C samples with RHA exhibits lower performance than the controlled sample and up to 500 ^{0}C samples with RHA exhibit better performance than the controlled one. These results are plotted in Fig. 4.



(a): Temperature Verses Strength



(b) Percentage of Strength Variation regarding to Control Sample at 32 ^{0}C

Fig. 4: Sample cooled in open air after Elevated Temperature

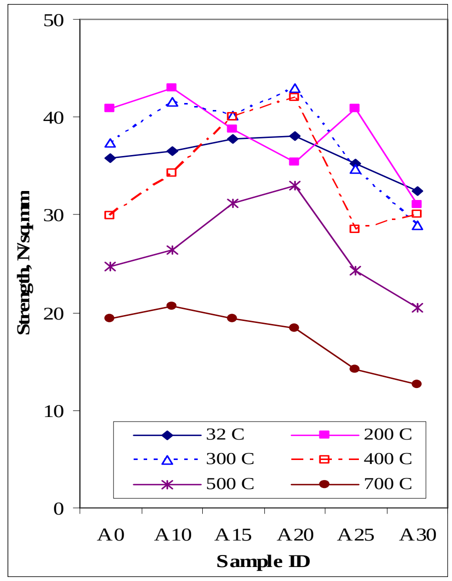
In case of samples quenched with water for 10 seconds immediately after removing from the furnace, mortar strength was dropped in most of the cases with respect to the samples cooled in open air only and the results are shown in Table 4. At 200 ^{0}C temperature, all the samples have lower strength except 10% replacement level followed by the controlled sample. At 300 ^{0}C temperature, sample having 10, 15 and 20% replacement levels shows higher strength than the strength at ambient temperature. This observation is similar to the samples which were cooled in open air only after heating. It was observed in Fig. 5 that at 400 ^{0}C, the compressive strength of samples with 15 and 20% replacement levels is still in increasing trend whereas the controlled sample lost 16.2% strength.

TABLE IV

Strength variation due to Elevated Temperature and quenched with water.

Sample ID	Temperature					
	32^0 C	200^0 C	300^0 C	400^0 C	500^0 C	700^0 C
	Strength MPa					
A-0	35.8	40.9	37.3	30.0	24.7	19.3
A-10	36.5	42.9	41.5	34.3	26.5	20.6
A-15	37.7	38.8	40.2	40.1	31.2	19.4
A-20	38.1	35.4	43.0	41.9	33.1	18.5
A-25	35.3	40.9	34.7	28.5	24.3	14.2
A-30	32.5	31.1	28.9	30.1	20.6	12.6

In Fig. 5 it is observed that at 500 ^{0}C temperature, controlled sample lost 30.9% strength and sample with 20% RHA lost only 7.6% compressive strength when the samples were quenched with water. And samples having 10 and 15% RHA also shows higher results than the controlled sample. Mortar samples at 700 ^{0}C temperature, with and without inclusion of RHA, exhibits lower results than any other temperature series. At this level controlled sample lost 45.9% strength regarding the strength without elevated temperature. Sample with 10, 15, 20, 25 and 30% RHA lost 43.6, 48.5, 51.5, 59.8 and 61.2% strength correspondingly.



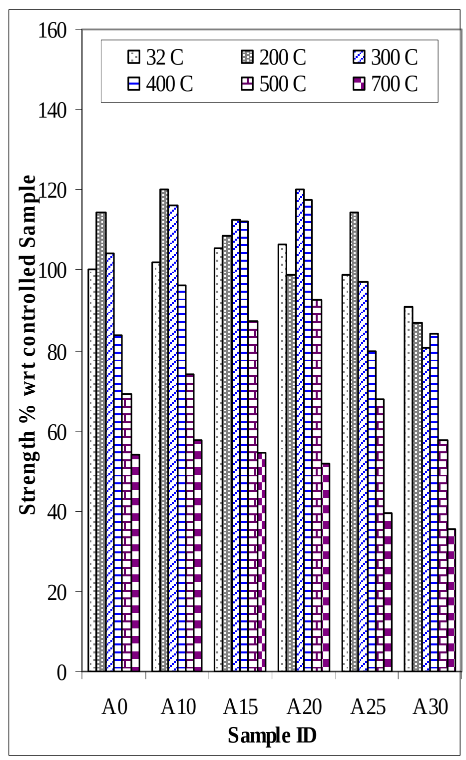
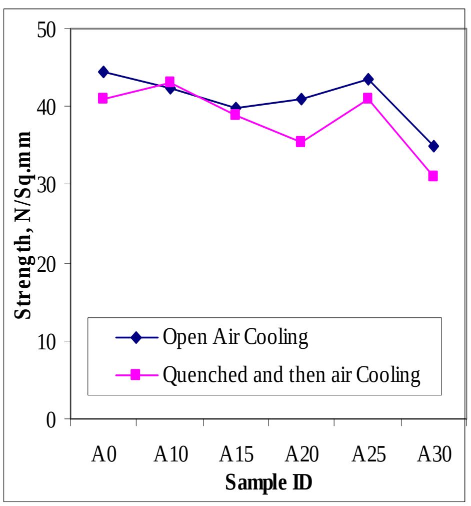
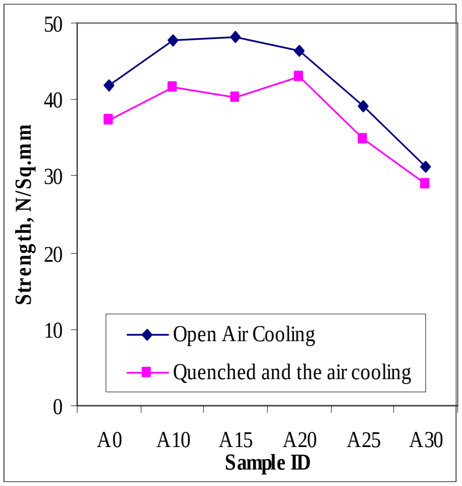


Figure 5: Sample quenched with water after Elevated Temperature and then cooled in open air.

The strength of all samples for 200 and 300 °CC was plotted in the graph shown in Figure 6. It was observed that the strength of controlled specimen at 200 °C temperatures was 124.4% and 114.3% higher at open air and quenched with water cooling condition respectively at ambient temperature. In case of open air cooling the controlled sample exhibits highest strength among all the samples and in case of quenched with water highest value shown in 10% replacement levels and which 120.1% is. At this temperature samples having 10% replacement levels shows higher strength when quenched with water than open air cooling condition. The Compressive strength of mortar increased up to a maximum of 135% for sample of 15 percent replacement levels in case of open air cooling and 120% for sample having 20% RHA in case of quenched with water when it was heated to up to 300 °C for controlled sample. All samples when quenched with water exhibits lower strength than the open air cooling after at 300 °C temperatures for 30 minutes.



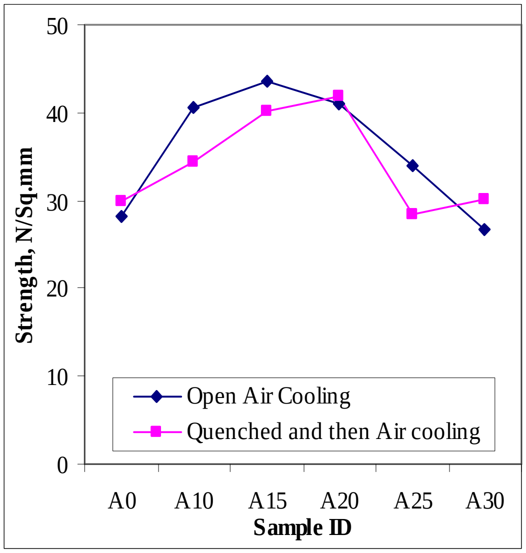
(a) Samples at 200 °C



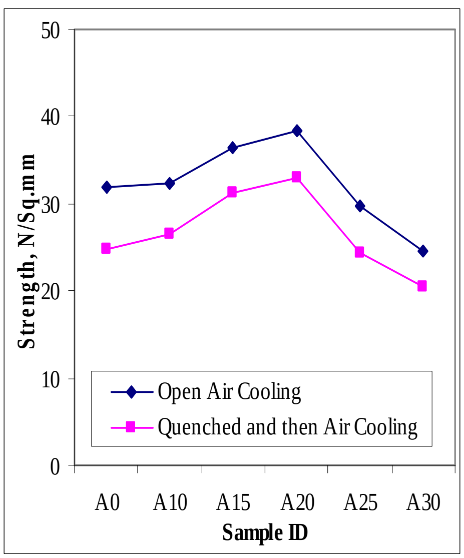
(b) Samples at 300 °C

Figure 6: variation in strength due to cooling system at Temperature of 200 & 300 °C

In case of open air and quenched with water the controlled sample at 400 °C exhibits lower strength than in case of ambient temperature. At this temperature samples with 10%, 15% and 20% RHA still showed increasing nature in its compressive strength when cooled in open air on the other hand when samples are quenched with water 15% and 20% RHA samples gain highest strength. All other samples at this elevated temperature showed lower strength when compared to the strength of ambient temperature. At 500 °C temperature all samples were dropping their strength in both case of cooling system compared to the ambient result. In the case of quenched with water the compressive strength shows 14% to 20% lower values than the samples directly cooled in open air. Figure 7 shows the detailed information about the samples facing 400°C and 500°C temperatures and cooled in open air and quenched with water.



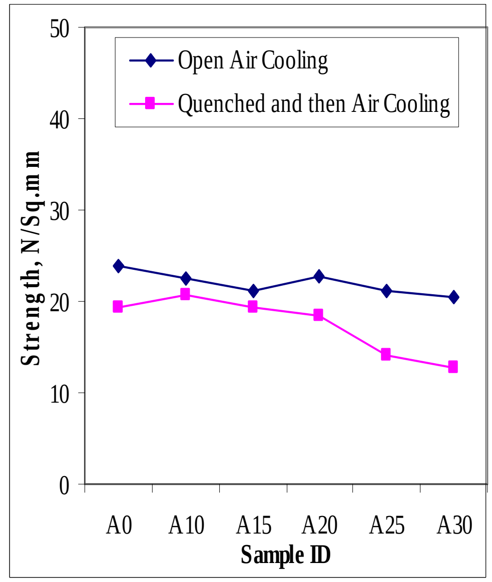
(a) Samples at 400 ^{o}C



(b) Samples at 500 ^{o}C

Fig.6: variation in strength due to cooling system at Temperature of 400 & 500 ^{0}C

Finally the strength was reduced to 67% when firing was performed at 700^{0}C and cooled in open air system for controlled samples. Samples having 10% and 15% RHA exhibits only 4.9% and 4.3% loss of strength when quenched with water in compared to the open air cooling system. This result is shown in Figure 7.



(e) Samples at 700 ^{o}C

Fig.7: variation in strength due to cooling system at Temperature 700 ^{0}C

The degradation of strength at elevated temperature is quite similar to the observation by Sarshar and Nassif et.al. on concrete cylinder [11,12]. Specimens were heated up to 500 ^{0}C and cooled by quenching with water by Bazant mentioned that the compressive strength is much lower than specimens not quenched but allow cooling slowly [13].

IV. CONCLUSIONS:

The following conclusions can be drawn from this research work

1. The addition of RHA as cement replacing material is quite satisfactory when the samples are in elevated temperatures.
2. At higher temperature the performance of mortar incorporating Rice Husk Ash shows better behavior on compressive strength than OPC mortar.
3. At 200 ^{o}C the controlled sample shows highest strength than any other samples when cooled in open air and 10% replacement levels exhibits highest compressive strength among all the samples when the samples were quenched with water and then cooled in open air
4. Samples having 20% RHA shows better performance up to 500 ^{o}C temperature for the controlled as well as other samples having different percentages of RHA.

5. The short time quenched with water of the heated specimens has produced significant effect on the compressive strength of mortar.

6. At 20% replacement level of OPC by RHA is accepted under elevated temperature.

V. REFERENCES

[1] Malhotra, H.L. The effect of temperature on the compressive strength of concrete. Magazine of concrete research, Vol 8 No 23. Aug 1956, pp 85-94.

[2] Zoldners, N.G. Effect of high temperature on concretes incorporating different aggregates. American Society of Testing Materials, 60/1960, pp1087-1108.

[3] Brams, J. A., Compressive strength of concrete at temperature to 16000 F; ACI publication SP25 Paper SP25-2; American Concrete Institute, Detroit, 1971.

[4] Nijland T. G. and Larbi, J. A. "Unraveling the temperature distribution in fire-damaged concrete by means of PFM microscopy: Outline of the approach and review of potentially useful reactions", Heron, 2001, 46, 253-264.

[5] St. John, D. A. Poole A. W. and Sims, I. "Concrete Petrography: A Handbook of Investigative Techniques", Arnold, London, 1998.

[6] Hansen, T. C. and. Ericsson, L "Temperature change effect on behaviour of cement paste, mortar, and concrete under load", J. Am. Concrete Insti., 1966, 63, 489-504.

[7] Castillo, C., "Effect of transient high temperature on high-strength concrete", MS. Thesis, 1987, Rice University, USA

[8] Lie, T.T., Celikkol, B.; 1990:" Method to Calculate the Fire Resistance of Circular Reinforcement Concrete Columns". ACI Materials Journal, vol. 88, No.2,pp 84-91.

[9] Schneider, U; 1985, " Behavior of Concrete at High Temperatures". RILEM committee 44-PHT, Kassel Tyskland 1985.

[10] Opheim, E., 1995 ; " Residual strength of fire exposed structural elements." Report 6.4, High Strength Concrete phase3. SINTEF-report nr STF70 A95205, Trondheim. Pp 29.

[11] Sarshar, R. Effect of Elevated Temperatures on the strength of different cement pastes and concrete. PhD thesis, University of London, 1989.

[12] Nassif, A. Y.; Rigden, S.; Burley, E. 1999, " the effect of rapid cooling by water quenching on the stiffness properties of fire-damaged concrete, Magazine of Concrete Research, No 4, Aug, p. 155-161.

[13] Bazant, Z. P.; Kaplan, M.F.; 1996, "Concrete at High Temperatures, Material Properties and Mathematical Models: Longman Group Limited.